# Search for Dark Matter Annihilations in Draco with CACTUS

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**Abstract.**
CACTUS is a ground-based Air Cherenkov Telescope (ACT) at the Solar 2 facility located near Barstow, California, and operated by UC Davis. It uses an array of 160 large solar tracking mirrors (heliostats) and a camera with 80 photomultiplier tubes, which, in a multiplexed fashion provides an effective camera with about 300 channels. By incorporating novel techniques of time projection imaging and triggering, CACTUS improves upon the first generation sampling arrays of its kind. We have recently completed observations of Draco, a dwarf spheroidal galaxy that is known to be rich in dark matter content. Supersymmetry-inspired models for dark matter predict observable annihilation rates producing gamma rays. We present the first results from our Draco campaign.

**Keywords:** CACTUS, Cherenkov, Dark Matter, Supersymmetry
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## OVERVIEW AND PHYSICS MOTIVATIONS

CACTUS is a unique instrument with a low energy threshold for gamma-ray observations. In a few months of operation during 2005, it observed several sources and measured excesses from them. In particular, our measurements of the gamma-ray emissions from the Crab nebula establish CACTUS' sensitivity in the 50-500 GeV energy range[1].

Cosmic gamma ray signals can provide sensitivity for new physics and complement searches performed at particle colliders. One well-motivated extension to the Standard Model of particle physics (SM) is supersymmetry, which relates particles with different spin [2] and introduces a new spectrum of particles: a boson for each SM fermion and vice versa. In Supersymmetric theories, if the lightest supersymmetric particle (LSP) is electrically neutral, colorless and stable, it is a prime candidate for supersymmetric cold dark matter (SCDM). In many regions of MSSM (and minimal supergravity) parameter space, the LSP is the lightest neutralino $\tilde{\chi}_1^0$, which indeed has these properties [3, 4] along with thermal relic densities compatible with that required by the cosmic microwave background and spatial distribution of galaxies.

If SCDM is indeed the correct explanation, dwarf galaxies with large Mass/Light ratio (M/L) would be prime candidates to search for SCDM. Self-annihilations of the $\tilde{\chi}_1^0$will lead to gamma-ray emissions either from pion decays or directly via the $Z\gamma$ decay mode. The case for ACT searches for SCDM has been made [6] and an early attempt [7] to use EGRET data from the region of Draco set limits on neutralino emissions.

The dwarf spheroidal galaxy, Draco, located $\sim$76 kpc away, is a companion of the Milky Way. It spans nearly one-third of a square degree but is extremely faint with a

luminosity of $\sim 2 \times 10^5$ $L_{solar}$. Detailed measurements by SDSS [8, 9] and Hubble [10] have established M/L = $92 \pm 28$ in solar units. Attempts to explain these results with tidal models [11] failed in the case of Draco [12] and a dark matter explanation is now favored [13]. SCDM annihilation rates will depend on the square of the density and hence the density profile is a very important component of modelling Draco, but there is less agreement on this score. Whipple took the approach of surveying 4 local group galaxies [14], including Draco, but did not see any gamma-ray excess.

## THE CACTUS TELESCOPE

CACTUS (Converted Atmospheric Cherenkov Telescope Using Solar-2) is a ground based air-shower detector located at the Solar Two site near Barstow, California. Solar Two consists of ∼1,800 large area (42 $m^2$) heliostat mirrors of which 168 are within the field-of-view of the CACTUS secondary mirror and PMT camera mounted ∼60 m above the ground level. The heliostats are individually steerable in elevation and azimuth, thus enabling the telescope to function as a directed instrument that can be used to track a celestial source. The cumulative tracking and pointing error for each individual heliostat is ∼0.1 arc-degree. CACTUS currently utilizes 144 out of possible 168 heliostats that are spread over an area of ∼20,000 $m^2$. The fill factor in terms of mirror area is ∼35%.

Details on CACTUS, its trigger and DAQ are available in [15]. Key features include: improved bandwidth (1.6 GHz) in the front-end electronics to suppress the rate due to the night sky background (NSB); use of time-multiplexing in the camera to capture light from more than one heliostat per PMT channel; implementation of a time-imaging technique to suppress hadronic showers and enhance the gamma-ray component in the data sample; world's largest mirror area of ∼20,000 $m^2$; trigger system that implements a majority logic on the entire camera unlike other heliostat-ACTs in which the camera is divided into sectors for triggering purposes.

Combining all these factors, CACTUS can be expected to have a low energy threshold suitable for measurements below 100 GeV.

## DRACO OBSERVATIONS AND FUTURE PLANS

The dwarf spheroidal galaxy, Draco, is an ideal candidate for an ACT search for dark matter. It is nearby (76 kpc away), has a small light background (integrated luminosity of magnitude ∼10.5) and is visible at $\sim 66^o$ above the horizon for CACTUS. During a 12-day campaign in July 2005, CACTUS performed a detailed Draco study. Data were taken in a drift scan mode, in which the heliostats were stationary.

The data set consists of 40 scans in R.A. in the vicinity of Draco. Control scans using Draco-$1^o$ in declination were also collected. We apply a procedure for removing NSB bias from the trigger in order to eliminate systematic effects. Figure 1 shows the results for these drift scans of Draco and 2 scans of Draco-$1^o$ in declination, using different pulse height requirements. In each figure, the corrected rate is plotted as a function of R.A. with Draco's center being approximately $260^o$. No indication of an excess around Draco is observed.

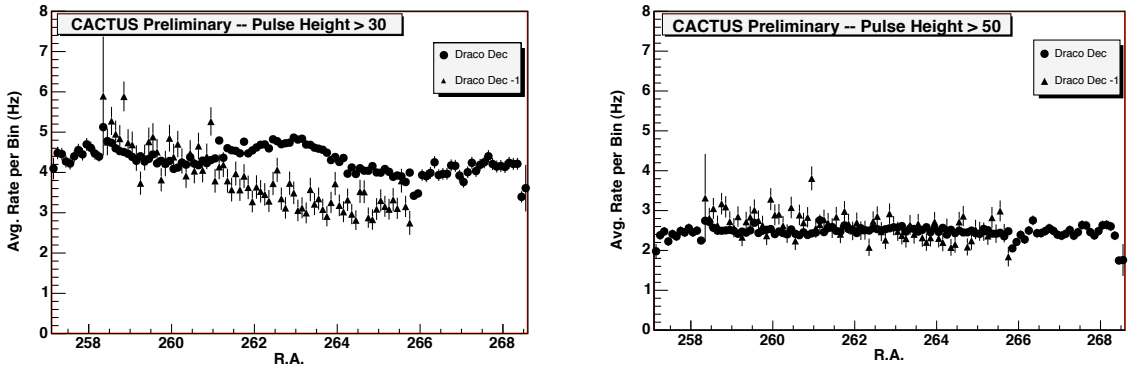


**FIGURE 1.** Average rate in Hz per bin for 40 drift scans versus R.A. for pulse height cuts of (Left) 30, and (Right) 50, where a pulse height of 50 is of order 100 GeV for gamma ray showers. Overlaid on each plot is a scan with same R.A. and declination Draco$-1^o$.

We are in the process of setting limits using the 2005 data. The CACTUS group will follow up on these first results with a second, longer study of Draco in 2006, which will also benefit from various detector improvements. This study will be followed by a thorough characterization of the observed flux and its implications for dark matter models.

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